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IN
BRIDGE DESIGN

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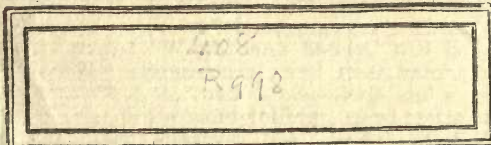
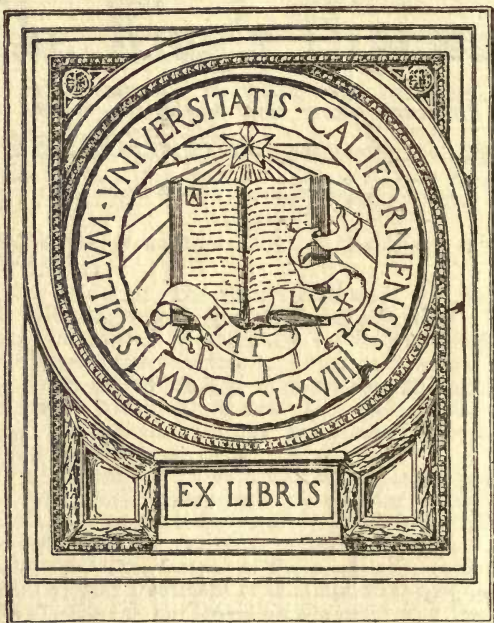
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PROBLEMS IN ENGINEERING WITH SOLUTIONS.

Being Questions and Answers reprinted
from the Assistants' and Students' Section
of "The Surveyor and Municipal and
County Engineer."

FIRST SERIES, 1909-10.

— Edited by —

SYDNEY G. TURNER, Assoc.M.Inst.C.E.

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PREFACE.

This book is a reprint of a series of articles under the same title which appeared in *The Surveyor and Municipal and County Engineer* early in 1912.

It used to be the custom to begin the preface to a technical or professional work with a more or less elaborate justification for its existence and some discussion of the ground covered by similar works. Nowadays it is more usual simply to put forward a book on its merits, regardless of whether the ground is otherwise covered or not. Sometimes the author is determined to "cut in," depending upon his publisher to find a sufficiently large public; and in this he is not always to be blamed, for many of the other books on his subject may be largely of the nature of compilations, while others are out of print, so that the extent to which the ground is actually covered by books which are readily obtainable cannot easily be ascertained. The responsibility must, in fact, be thrown upon the shoulders of the reviewers.

It is sometimes the case, however, that the author of a book, building up his arguments on basic principles, and conscious of a powerful impetus, knows that what he produces is not tainted with plagiarism or stuffed with compilation: it may be good or it may be bad, but such as it is it is sufficiently original to be considered on its merits. It is hoped that PRELIMINARY STUDIES IN BRIDGE DESIGN may be regarded as a work of this character.

There are many books on the design of spans and some on the design of bridges; but most books on

bridges treat of the accommodation for the river or stream rather as an item than as half the story, and very little that has been written about the behaviour of streams and rivers is specially intended to throw light on the nature of river crossings. The keystone of the little book which is now offered to the public is the consideration that an ordinary highway bridge is as much a crossing of the road by the river as it is a crossing of the river by the road. If a main road, for instance, crosses five streams in a distance of five miles without any important change in the character of the road itself, it is clear that though the width of the road may be changed at some of the crossings the chief interest in the designing of the bridges lies in the different problems presented at the five crossings and the differences in the characters as well as the sizes of the streams.

The most suitable bridge will be one which is designed not only in view of what the engineer finds at the actual crossing, but in view also of the nature of the stream as disclosed by its past history and as disclosing its probable future behaviour.

The book is intended to provide the student with a foundation for the study of bridge design, and, at the same time, to suggest to the experienced engineer that some of the facts which he takes into account in designing bridges will have more significance and greater value if he will study them in the light of the basic principles which really hold some of them together, and separate these from others. Thus the recognition of the three types of streams and the five primary types of bridges is intended to create, as it were, a landscape and an atmosphere in which the study of bridge design can be approached, before taking into consideration the great primary facts of mechanics such as mass, weight, friction, moment or leverage, and the various manifestations of the cohesion of materials. The study of these, first as affecting the choice of type, and next as affecting the actual form of the bridge, will be considered in

the second and subsequent volumes of the series, of which this little book is the first. At the same time, Part I. has been written, and future Parts will be written, so that each may stand alone.

The author has made a genuine attempt to write of preliminary studies in a way which is an introduction to the subject itself and is in no sense dependent for its value on what he himself may write afterwards. Similarly, the successive Parts will be written so that each may be fairly described by its own title, though it is of course to be hoped that the series as a whole may have some special value.

And now a few words may specially be addressed to the student. Many of them will, sooner or later, put in some years, or find their careers, abroad—in India, South Africa, or other countries of the Empire. The chief differences between bridge-building in these countries and bridge building at home are two : First, the streams that will have to be dealt with are often uncontrolled, or are only controlled here and there where villages and towns are threatened by their action upon their banks ; whereas at home the streams are much more under control by water-supply reservoirs and ponds which reduce the floods and sometimes maintain the flow in dry weather, by flood banks and by permanent pitching of the banks where they pass towns, and in the country by steady work in bank protection done by farmers and land-owners. It is, however, quite easy to find in almost any part of the British Isles small streams from the behaviour of which movements and changes of the same character as those that take place in the courses of larger rivers can be studied. There may also be such evidences of the past history of the streams as will be of help to an understanding of the larger streams abroad. There will also be many examples of local protection or training works, and where a single work occurs in an otherwise untouched stretch of some length it will be possible to see the kind of action that goes on when a single work of the same

kind is carried out in connection with the building of a bridge.

The kind of stream that best repays study is a fairly rapid brook, big enough to be a trout stream, and flowing through a country containing only a few villages. It will provide examples of erosion, of cutting back, and of scours which last in the same state for a long time ; while, if the valley is flat, there will probably be examples of spills or short-cuts in various stages of development. For a study of the unrestrained action of a stream it will usually be necessary to go to an upland valley in a wild part of the country. Generally, for the effects produced by a stream in floods, a fairly large river should be visited when a flood is at its height.

The second important difference between conditions in the British Isles and those abroad lies in the fact that at home the site of the bridge is usually fixed, or is fixed within small limits of deviation ; whereas there is often the opportunity in a comparatively undeveloped country of building the bridge at a specially favourable site. It is also usually important that this should be done, either on account of first cost or in order that the crossing may be a lasting one, even if the span or the whole structure be replaced later on.

A general study of river crossings is one that can be pursued under especially favourable conditions in the United Kingdom, owing to the great variety of geological and topographical features which may be met with in a small area.

Preliminary Studies in Bridge Design.

The various types of stream crossings have been evolved from five primary types, all of which are still to be found in their simplest forms. First, there is the crossing at the "narrow," where the stream runs through a chasm, or in a sharp bend against a hillside, or where it is engaged in cutting back a rocky ledge. On small streams these narrows were jumping places, and were first bridged by trees felled by the stream itself, then by trees felled purposely by man. The earliest arch bridges of single span were probably those across chasms with hard, rocky sides, since no abutments were required, and it seems likely that the first of these were built without the use of centreings, in the way that short spans are made to-day in Moorish Spain. The abutment, consisting of blocks of stone piled up to resist the thrust of the arch, or, in the case of a beam, of stakes driven down to prevent the span from being washed away, was probably of considerably later origin than the span itself.

The second type was evolved from the ford, which in its simplest form is a gravelly shallow, or rocky shelf. In this case the piers, in the form of large stepping stones, jumping stones, or "jumping islands" of heaped shingle, were no doubt of earlier origin than the spans, which at first were slabs of stone or logs placed across the stepping stones. The next stage was reached when the slabs were placed so as to resist being swept away, providing

a bridge at low water and a ford during moderate freshets, a form which is of importance to-day as a crossing for wide, shallow rivers. The pile and beam bridge may be regarded as belonging to this type, since it is a development of the crossing stakes of a deep ford.

The third type is the suspension bridge. Suspension bridges may have been evolved from the guide rope of a ford, but the type must be regarded as quite distinct because it includes bridges in which use is made of the action of gravity as a means of crossing a stream. No doubt in its earliest form this type was merely a rope of twisted creepers, tied from tree to tree across a stream, but the advantage of having two ropes, each tied high up on a tree on one bank, and reaching the ground on the other bank, led to the evolution of a form of bridge which to-day plays an important part in transport and communication in the Yün-nan provinces, and seems worthy of adoption in other places where it would be an economical crossing. In the same country (Yün-nan) there are many chain bridges, with roadways of planks. In his book "Yün-nan" Mr. H. R. Davies mentions bridges of spans up to 225 ft. and 240 ft., consisting of ten or twelve chains. In some cases the chains are passed round natural pillars of rock, and in other cases they are imbedded in massive piers of brick or stone.

The fourth type is evolved from the permeable dam, the beavers' dam, or the jam of logs and branches by which an angler may sometimes cross a stream dry shod. The earthen bank, pierced by culverts, belongs to this type, in which we have the principle of pooling up to obtain sufficient head to pass the water rapidly through relatively small openings. Similarly, heading up to obtain a free fall may be adopted in order to make a rapid which will provide a shallow ford. When, however, this amounts to forming a weir with stepping

stones, or small spans along its edge, the bridge really belongs to the fourth type. Where hard materials are available this form is a useful one at suitable sites. A low weir at the head of a rapid provides a free fall; the velocity is great, the waterway is reduced, and the amount of masonry required for the bridge itself is therefore small. Where stones abound, and where the site allows of its construction, a temporary bridge belonging to this type may sometimes be made by heaping up stones in imitation of the barriers which dam up some mountain lakes, the water passing through but not over the stones.

In the fifth type, which may be regarded as of modern origin as far as its application to road crossings is concerned, the principle involved in giving a high velocity to the water is carried further than in the fourth type, and the problem may be regarded not so much as that of carrying a road across a stream, but rather as that of taking the stream across the road with the maximum allowable velocity, and therefore the minimum cross-sectional area. It may be used economically where circumstances are favourable, but the crossings for which it is the most economical type are somewhat rare, though the principle of speeding up the water is in itself of considerably wider scope.

Engineers will find that this classification of bridges into five primary types will add to the interest with which they regard the various bridges which they see when they are abroad, while such a classification is by no means without value in the matter of choosing the type of bridge for a particular crossing, and in devising crossings of a cheap or temporary character. In many cases it is worth while to consider each type as regards the possibility of its supplying a candidate for the final comparison of definite designs; but, as soon as definite *forms* have been brought into the comparison, the existence of the five primary types,

though present as a background in the designer's mind, must not be allowed to hamper specific comparisons.

THE PROBLEM AS A WHOLE.

x The problem involved in making an economical river crossing must be regarded as a whole; the cost of works of diversion or training must be as carefully estimated as that of the structure itself, and the effects of the work in making it necessary to protect the banks or bed of the stream must also be fully considered. At the same time, probabilities must sometimes be balanced against facts, for a work which considerably disturbs the existing conditions may be much cheaper both in first cost and in the long run than a work which does not disturb the conditions. It is easy to see that it will not be economical to bridge a shallow stream 300 ft. wide by means of a single span with abutments untouched even by floods; but it is less easy to see that it may be worth while to reduce all the costly part of the work to a width of 60 ft. or so in mid-stream. Yet this may sometimes be the case. It is hoped that the studies which follow may be useful in helping young engineers to think, in the matter of the design of ordinary road crossings over streams, as well as in suggesting simple and inexpensive means of providing crossings, sometimes of a temporary character, pending traffic developments, and sometimes as permanent works where more costly ones cannot be afforded. Both at home and in the colonies there is scope for work of this kind, since at home we encounter, on "tertiary" roads and by-roads, crossings which offer varying degrees of impediment up to the point where it becomes absolutely necessary to make a bridge, while in the Colonies there are many important routes which are impeded here and there by crossings which are not likely to be provided with good bridges for a long time to come.

In the first place it is necessary to make a distinction between impediments which are permanent, such as a deep gorge or a perennial stream always of considerable depth, and those which are temporary, such as places which are now and then flooded, but the crossing of which at other times presents little difficulty. At the same time, the latter class often present a permanent impediment of a less severe nature, as well as the occasional impediment of a more severe nature. In some cases it may be economically sound to take measures to overcome the former; in other cases it is more worth while to make adequate provision to meet the temporary impediment. For instance, where the sandy bed of a usually dry river is a serious obstacle, causing delay, tiring draught animals, and jeopardising motor vehicles, it may be worth while to pave the portion of the bed at the crossing in order to destroy its foundrous or rough character, protecting the paving from the scour of floods, but taking no measures to provide a crossing at times when the river is running several feet deep. A decision on this point depends upon the amount and importance of the traffic, the usual duration of the flood, and the distance of the nearest bridge. Supposing, however, that a river has a firm, gravelly bed, and gently sloping banks, and can easily be crossed at ordinary times, it may be desirable to spend the available funds in providing a ferry which may be used when the river is too deep to be forded, or in making a road which will shorten the distance to the nearest bridge. Works of both classes may be found in various combinations. The main point to be borne in mind is that some measures of value, however arbitrary, must be assigned to reduction of effort and reduction of delay, in order that the relative values, as well as costs of different proposals, may be estimated. A good ford of ample width may be better than a narrow bridge which will not take the



FIG. 1.

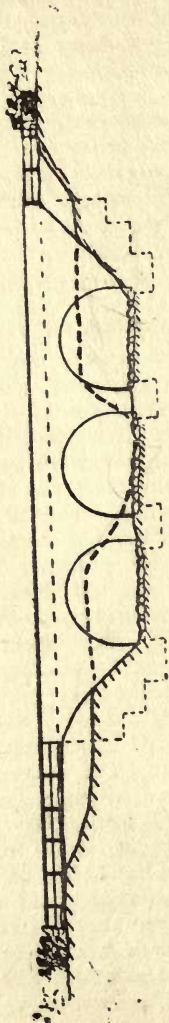


FIG. 2.



FIG. 3.

heaviest vehicles, these being taken with difficulty through an unimproved ford. In another case a bridge, however light, may be badly needed. A satisfactory ford, suitable for a warm climate, and where the natives have no objection to wading thigh-deep, is no precedent for a similar work in a cold country where boots are worn. An intermediate type, between a bridge and a ford, is suitable for many crossings such as those of wide Indian rivers. At ordinary times the structure is a bridge, but during freshets it is a raised ford, the water passing over the top as well as through the vents.

CONDITIONS AT THE SITE.

In making the preliminary survey and estimates there are some conditions which can be fixed at once within moderate limits of divergence, and others which can only be found with some trouble. In the case of a bridge or causeway we may be able to decide at once that, for the sake of the traffic, we will not make the road rise above a certain level nor depress it below a certain level. If the stream runs in a deep bed, and it is shown by calculation, or by what happens at other bridges near the site, that the waterway can easily be made ample, it is not difficult to fix the length of the bridge proper between the approaches. In another case, where the stream runs in a shallow valley and in a shallow bed, it may not be enough to make a span or spans equal in area to the cross-section of the stream flowing full as in Fig. 1. On the other hand, we must not jump to the conclusion that the amount of water passing down can be judged by the width and depth of the stream and the flooded parts on both sides of it; the discharge must be calculated at some place where the average velocity can be estimated with reasonable accuracy.

When the bed is not big enough to take the whole of the discharge in times of flood, it may be a matter for careful consideration whether we shall

enlarge the bed at the site and a little above it and below it, blocking the rest of the valley below road level with an embankment as in Fig. 2, or whether we shall make the vents in the bed of the stream sufficient for the ordinary flow only, providing flood vents on the higher ground on one or both sides, as in Fig. 3. It may not be necessary to do either if the bed of the stream falls steeply enough below the site, because in that case the heading up of flood waters against the embankment may give the water sufficient velocity to pass the whole flood discharge through an opening no wider than the bed of the stream in normal flow.

THREE TYPES OF STREAMS.

Before discussing the design of the bridge, it is necessary to know to what type the stream belongs. We may, for the purpose of classification, distinguish three types: (a) A stream which has cut itself an actual bed below well-defined banks, and sufficient to take the maximum flood discharge; (b) one which, while running in a well-defined bed, demands, in addition, a flood channel; or (c) a stream which may change its course suddenly or gradually.

Let us take first the case (a) of streams in deep beds sufficient for the greatest flood discharges. This will include those which, after a long drought, and especially after a succession of dry seasons without any big flood, flow in a reduced channel. The higher parts of the banks and low-lying places usually flooded each year may be partly occupied by bushy growths, and such places should be recognised for what they are, and should not be occupied by permanent works which are not intended for such situations. Downstream of the bridge it may be necessary to clear away such growths from time to time. Such a stream may change its course very slowly, but in a settled country this is seldom a serious matter to a bridge designer, having regard

to the resources of the country, the other interests involved and the small choice of site. The persons responsible for the bridge will not, as a rule, be alone in wishing to keep the stream from attacking the abutments or approaches. In a newly-settled country, however, where there is usually a choice of sites, and where financial resources are often small, a tendency to movement of the bed of the stream may be a serious matter. There is no confusion here with streams of class (c), the definitely wandering type, nor is it forgotten that a tendency to movement of the bed may take place in the case of a stream of class (b). In the latter case, however, the matter is not usually so serious, and it is convenient to consider it under class (a), which includes most of the swiftest streams.

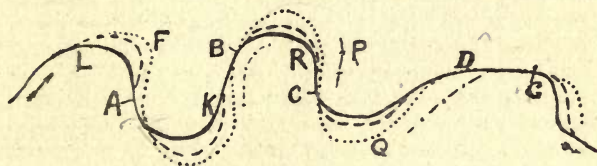


FIG. 4.

THE ATTACK ON AN ABUTMENT.

If a stream in a deep channel tries to change its course, developing a set against one of its banks, it may make a strong attack upon the abutment of a bridge, and outflank it or destroy it.

It is important in such a case to build the bridge where the stream is least likely to change its course, or, if we cannot do that, do one of two other things. One of these is to anticipate the next move of the stream, and so lengthen the period of the next phase as far as that particular reach is concerned. The other is so to design the abutment that it may stand alone if necessary. Let us consider the three cases as applying to a stream in a fairly deep bed which is sufficient, or nearly sufficient, for

the flood discharge. The diagram (Fig. 4) represents typically the course of a stream or river. There are, from the present point of view, good sites at B, C, and G, and of these G is the best, and B the next best.

THE SITE ON THE STRAIGHT REACH.

Generally the best sites are near the downstream ends of straights, and for choice a straight like D G, which is in line with the general direction of the stream. This is because the stream tends to move its bed as shown by the dashed and the dotted lines, and although this tendency may be resisted for very long periods where the soil is hard, it must be regarded as a serious matter where the soil is soft. In any ground less hard than rock it may be serious, and the engineer has to decide what is the measure of its probable importance in any given case. Each curve tends to move forward, more or less in the direction of the straight above it. As regards the curves to right and left of the main course of the stream, the lengthening of this part of the course in a direction not directly down the valley, but more or less across it, results in a reduction of the fall or slope, and a consequent slowing of the stream. The attacks upon the banks at the ends of such reaches are therefore relatively feeble, and the bed tends to silt up in the part between a bend to the right, say, and the next bend to the left. On the whole the curves tend to move downstream, each curve pushing its way on by erosion of the bank. The longer the straight reach above any point, such as B, the longer will it be before this action reaches B. Taking the points A and B at the period denoted by the dashed lines, A is now at the head of a straight, and liable to attack, while B is as yet in the middle of a straight. Later on, the phase denoted by the dotted line B is beginning to be attacked, the stream tending to move towards the position shown

by the chain line. The action must have its limits. As the bed lengthens and the fall diminishes there is a tendency to silting up and a raising of the actual bed of the stream. If it is a small one the reduced velocity, by allowing of encroachment from the banks, still further reduces the capacity of the channel. When a big flood comes the channel has not sufficient capacity for it, and it flows across from bend to bend. This may happen several times, and in the case of a river in class (b), a river which has a flood channel, it may be the usual condition. But sooner or later a weak place is found in the bank at the lower of the two bends, and cutting back from this the flood waters establish a spill channel which is deepened by successive floods, deepened later on by taking a part of the normal flow, and finally becomes a part of the river-bed proper, leaving the bend as a pond, which, if the river be liable to floods, will gradually silt up. We now see why the bend which had reached the limit of divergence from the main course would not be a good site for a bridge. When, however, the soil is hard and the river is not a swift one the kind of action described may be so slow that, as far as the present generation is concerned, it can only be called a "tendency." Even then the amount of cutting action at a bend may be sufficient to make the site a bad one for a bridge which should, other circumstances permitting, be built near the downstream end of a straight. If the soil is soft and the cross-sections of the valley very flat the river may belong to the wandering type, in which case we see why G is the best site. Whatever happens the reaches L A, K B, and R C can only have a life through one phase, and they are discarded when the river makes short cuts and starts on fresh curves. But short cuts occurring above the reach D G may be such that D G is still a part of the bed of the river, and it may remain so through another phase.

This consideration, however, only applies to streams of the wandering type.

Even when building a farm bridge across a meadow brook it is worth while to put it on a straight, or at any rate not at a sharp bend. Another plan, applicable to ordinary highway bridges, is to choose a bend where the stream is not in the alluvial soil of the valley bottom, but is up against a bank of solid ground. In many cases, however, such a site is a bad one, because one bank is much higher than the other. Where an old valley road, bridle path, or "trail" which crosses from one side of a valley to the other is being improved, and it is found that the crossing is at such a bend, it may be worth while to divert the road in order to get a better crossing. When the stream is a small one, and the bends are on a small scale, a very little diversion of the road may make an important difference, and in this connection it must be remembered that the best place for a ford is often by no means the best place for a bridge, or even the cheapest, counting the necessary road diversion to a better site. This sometimes makes the improvement of an old bridle path into a good road a matter of difficulty, as the path crosses the rivers by the fords.

Supposing that the site is necessarily fixed by other conditions, the usual case in old countries, we must study the course of the stream for some way above the site, or, if it is maintained in a certain course, we have only to consider the nature of any attack that may be made on one abutment or the other. We may decide to train the river if necessary, or to maintain the banks by pitching or otherwise. In other cases, if a good fall can be obtained below the bridge, it may be sufficient to make very deep foundations and lower the whole bed under the span, taking the stream through at a high velocity. This may entail some pitching, and careful estimates of the cost of this should

be made. It is not enough to say "we shall pitch if necessary." If the odds are two to one against pitching being needed a charge of a third of the cost of the estimate, say, should be made to that particular design.

If the chief fear is that scour will take place at the foundations, not for short periods and only during floods, but all through the year, this may be lessened by obstructing the stream below the bridge, so that the water will be deeper and will flow more slowly. To allow of this the waterway must be amply sufficient for the flood discharge. Deepening the water by raising the surface level tends to the protection of the foundations by deposits of silt or gravel, and reduces scour of the banks by reducing the velocity. This principle is especially useful on streams which flow through soils which contain few pebbles; but when the quantity of gravelly material at the bottom is considerable, it may be better to make a bridge with shallow foundations at a wide and shallow place, for instance, in a part of a scour, provided that the edge of the scour is not being cut back at a rate sufficient to threaten the bridge.

DEEP FOUNDATIONS AND SHALLOW FOUNDATIONS.

Engineers sometimes speak as if there were two schools of bridge designers, one school preferring to put down deep foundations beyond the reach of scour, and the other preferring the type of bridge with shallow foundations, with a pitched floor under the arches, and more or less pitching up and down stream. This distinction is all wrong. Given the limits within which the road level may be raised or lowered, and assigning some weight of objection to such raising and lowering as well as any actual cost in approaches, there is a design of bridge which is the best for the particular case, and it is the business of the engineer to find out what that design is. It may happen that either

of two distinct types is thoroughly satisfactory, and the costs the same, and if the work is a small one it is not necessarily worth while to pay the fees or costs of estimates required to determine what is the best type. But it usually is worth while. If a simple culvert can be built for £25, it is not worth while paying a £5 fee and £5 for alternative plans, in order to reduce the cost to £17; but

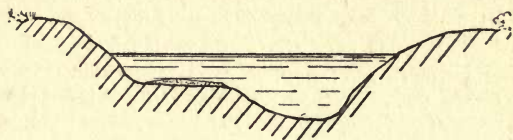


FIG. 5.

when a bridge is going to cost several hundred pounds it is usually well worth having alternative estimates, seeking for what is the best design for the particular case. Still more in thousands. The deepening expedient should not be adopted unless recommended by an engineer of experience. Its



FIG. 6.

efficiency depends a good deal on the relation between ordinary flow and the usual floods, under the conditions to be imposed. If the depth of water is such as to prevent the growth of reeds and similar plants, the effect may be to increase scour. On a wide stream the growth of protecting bushes on the banks may be advantageous, and especially the formation of a marshy berm, while on a nar-

rower stream such a development may narrow the waterway too much.

BERMS.

If berms are made for a little way above the bridge, the level chosen should be such that they will not be submerged long enough and deeply enough to kill the plants with water, nor left dry long enough for them to be killed by drought. Compare Figs. 5 and 6. The floods will then flow over a resisting bed with slack waters against the banks, and whatever scour does take place will be comparatively easy to make good, for it will not bring a mass of earth and sods sliding down from above. This kind of protection may be compared as to cost with the method of cutting away the bank at a slope and turving it; and that of digging away the bank and replacing it with layers of withies (assuming that the climate is suitable); or it may be combined with these, the bank below the berm being made up with withies and the bank above it as a grassed slope. Similar work may be done for a little way below the bridge. In Fig. 7 an attack at B, instead of causing a slide of the bank from D to the bed, only cuts away a piece of the berm.

It is not always worth while to do work other than that on the bridge itself, and if there be any doubt alternative estimates may be compared, thus:—

- I. (A) A cheap bridge, (B) work on the banks, (C) occasional work of maintenance; and
- II. (a) A more costly bridge, which hardly disturbs the course of the stream; (b) no other work; (c) occasional fairly heavy repairs of damage to the banks, caused by the set of the current.

STREAMS WITH FLOOD CHANNELS.

Let us now consider the case of a stream which runs in a permanent bed, but has also a well-

defined flood channel which, at any given place, may be on one or on both sides. The condition may be natural when, speaking in a geological sense of time, the stream is not old enough to have worn down a bed sufficiently deep and wide to take its flood discharges. If it is not tending to this condition—that is, if the tendency in the part under consideration is towards accumulation rather than removal of material, it will come into class (c), which we are not now treating of. In settled countries the condition is often an artificial one. Except in times of flood the stream flows in a defined, but often somewhat shifting, course, while in flood times it overflows its banks and spreads on each side till it reaches the flood banks, which are usually made roughly parallel to its main course and do not follow the windings of the stream proper. When a road is to be made, or an existing road improved, across such a valley the choice of a place where the fall of the valley is relatively sharp has this advantage, that the velocity of the stream will be greater and the waterway of the bridge smaller. Besides this, the flood banks may usually be placed nearer together at such a place than they are where the valley is flatter, and if approach embankments are not made—to the bridge—the total cost of the work will be less. On the other hand, a wider place, between flood banks, and where the bed of the stream is about half-way from one to the other, has this advantage, that after the bridge is built there will be less likelihood that the current will set against one of the flood banks and breach it. Supposing that the flood banks not only prevent the inundation of the valley outside them, but are also, in times of flood, the actual banks of a flowing stream with very little slack water, it is clear that a bridge which will not obstruct this waterway may be a costly work. In such a case it is worth considering the cost and expediency of making an actual bridge

for the stream proper, and designing the rest of the road between the flood banks as "road dams" (to be described later), each approach to the bridge proper being a ford, only slightly raised above the level of the ground. In such a case at least a narrow plank bridge should be provided for foot passengers in countries where there is need for it. They are not required in country districts in India and other warm parts of the world where foot passengers do not mind wading.

But, taking the typical case, when the whole width of the flood channel is not occupied by water moving downstream with considerable velocity, or when the flood channel is that between natural slopes admitting of some heading up, let us consider what are typical designs.

TYPICAL METHODS

One plan is to provide an ample opening for the normal stream and ample openings in the embankment across the valley. That is to say, we make the whole work in such a way that the flow is scarcely impeded at any time. The opening in the bed of the stream will be such that it will not leave its course any sooner than before on a rising flood, and the other openings will pass the water with no sensible heading up and no important difference in the set of the current. This type, or a reasonable approximation to it, is usually a suitable one when the site is not far below a town or village.

It is not, however, always necessary to build such a bridge, which may be very costly. Heading up may be allowable or even desirable. The case in which it is desirable is when the site is above some other obstruction which is in jeopardy during high floods, or when it is desired to preserve the lands below the bridge from the full effects of a flood. This is a matter for calculation.

THE BRIDGE AS A CHECK ON FLOODS.

First we measure or estimate the discharge of the stream when in full flood, and decide what new flood level is permissible above the work. We then design (provisional) vents which will just pass the whole flood discharge at this level, and with the effective head, the difference between the level above the bridge and that below it. The latter may usually be judged without calculation if there is a rapid below the bridge, or it may be calculated from the cross-sections, and the longitudinal sections of the bed and the flooded channel. We now calculate, from the areas of bridge opening which come into play at different levels, and from the corresponding differences of levels above and below the bridge, a series of increasing discharges which will all be less than the maximum discharge, and each of which will correspond to a certain amount of pooling above the bridge. As this pooling is over an area which can be measured, we are able to find for each stage how long it will be till the water has pooled up to the next stage. The sum of these periods is the period during which the flood is checked. We may repeat these calculations with different sets of vents until we are satisfied with the result.

If the water actually rose to this highest level the full flood discharge would pass, and there would be no protection; but, although this is allowed for in calculating the areas of the vents as a measure of precaution, the water would not really rise to this level, nor would the discharge reach this rate because that maximum discharge continues only for a short period, less than that of the whole time of pooling up. If, however, the duration of the period of nearly maximum discharge is not considerably less than that of the period of pooling up to maximum level, it is not worth while to do the work in this way for the protection of the

village, and if there is no other reason for following the design foreshadowed thus, the papers can be put on the file and the problem attacked afresh. The calculations will not have been wasted; they have narrowed the issue.

POOLING FOR HEAD.

If it has been decided that it will be cheaper to have a relatively small opening with high velocity in time of floods, with local protection against scour, rather than the provision of a bridge with many or large openings, the pooling up necessary to give the high velocity may be allowed for that reason, and the vent or vents in the main stream may be enough to pass all the flood water. In case of choking of the vent, or if there is doubt as to the maximum flood discharge, other vents may be provided at higher levels in the flood channel. In any case there will have to be a vent which will pass the normal flow with a head of water allowable during times of normal flow.

The main principle involved is an important one. On a rocky site we may be able to block the valley by a plain earthen bank, the only work in which is a relatively small culvert or bridge in the bed of the stream. Where the fall of the valley is steep the flooding caused by doing this will be small, and in a wild country may be a matter of no importance. In such a case blocking of the culvert might lead to the bank being overtopped, and this point must receive full consideration. The principle is not only applicable to rocky ground. The vents needed for a sluggish stream in a hard soil, or a stream with banks well protected by vegetation may be of such size that with the additional heading up needed to pass flood waters the velocity below the bridge is not excessive, or the discharge may be into a large pool which harmlessly receives the water.

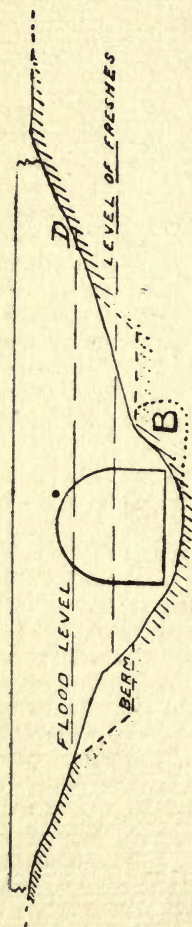


FIG. 7.

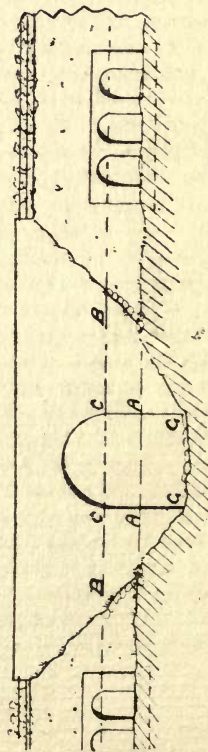
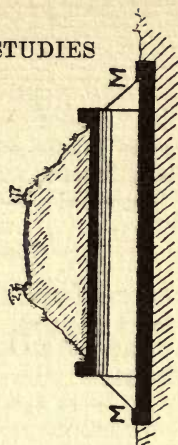


FIG. 8.



THE NUMBER AND SIZE OF ARCHES.

It is often the case that an arch which is high enough to take the road, and of so wide a span that the abutments keep the approach banks out of the way of scour, is large enough to pass all floods. In other cases its total area is sufficient, but it is not wide enough, and the area at an allowable water level is not enough. In that case the desired capacity may be gained by making the arch of wider span, by making more arches, or by placing relief vents in the approach embankments. If low arches of small span piercing the embankments will suffice to pass the flood waters, it is a mistake to spend money on increasing the waterway of the main arches with the deeper foundations, unless it is necessary to keep down the water level in times of flood. These arches in the river bed must in most cases have their crown only a little below road level, often high above the flood, while this is not necessarily the economical design for the arches piercing the embankment in the flood channel. In the diagram (Fig. 8), if the area $A C C A$ be not enough to discharge the flood at the level $B C C B$, then it is usually cheaper to provide two or three of the small spans rather than another large one.

A beginner may ask why it would not do to have small vents instead of the area $A A G G$, with its massive masonry. This would be somewhat like the case already cited: blocking the valley and providing small vents, though without the high velocity. In a case such as that which we are considering it would usually be uneconomical or undesirable for some or all of the following reasons: First, the culverts at the depth $G G$ would have to have a length somewhat greater than $M M$ on the cross-section, the width of the bank. This would make them more costly than culverts at the higher level, and they would not

pass more water than culverts just submerged in the flood channel unless the valley fell away rapidly below the bridge. They would not, however, cost more in many cases than the one large span. Secondly, because they would be a part of the main bridge and their permanence an important matter, they would have to be built more solidly than the relief culverts. Thirdly, being subjected to scour, they would have to have deep foundations, unless a pitched floor were provided; and, lastly, the position and size of their abutments would bring the ends of the embankment nearer the stream and render them more liable to attack. In addition it must be remembered that in many cases the width and height of the largest span are determined by the width and headway necessary to pass floating timber or other flotsam. At the same time there are crossings not unlike that shown on the diagram, for which it is worth while working out alternative designs between the limits, in the one direction of a single large span, and in the other direction of an embankment of full width pierced by culverts. A good deal depends upon the slope at which the sides of the embankment will safely stand, for this determines the lengths of the culverts. It is not difficult to find examples of single high arches in situations where the bank and culverts would be the cheaper form.

When the bed of a stream in a much larger flood channel is only a little below the level of that channel and floods are frequent, it may be a good design to make a fill at about that level, blocking the bed of the stream and placing a number of small vents at the higher level. In such a case, and some which are similar as regards the main idea, it may be worth while to avoid the actual bed altogether to save the cost of making the deeper foundations into solid ground, such as Q (Fig. 9). This is quite an allowable method of making a semi-permanent crossing in

a new country, and has, in such a case, the advantage that if a larger span is afterwards made for the stream itself, the original openings may remain, serving as flood openings. The design is sometimes suitable as a permanent one, and may even be the best and most economical, first and last.

WANDERING STREAMS.

We have now to consider the third class of streams and rivers, those which change their courses, suddenly or gradually. If we are thinking geologically the class is a very large one, but for practical purposes it only includes those in which the change is rapid, taking ordinary measures of time. A river of this class may desert a bridge which has been built across it and wander off on quite a different course. Such cases are by no means very rare, particularly in India, and the same principle is at work in deltas, where the relative sizes of different branches often vary very much in the course of time. Sometimes there is a long struggle to keep the river from outflanking the bridge and breaching the road. In other cases there is a bridge spanning the dry bed of the river, and when the rains come the river does not appear; or it flows for some weeks, when it succeeds in breaking through some barrier further upstream, and gradually makes a bar across the old bed. Lastly the deviation may occur in a sudden flood after a long period of gentle flow, or occasional small freshets, during which the vents have become choked, partly by silt, partly by bushes, and partly by drifting sand. The obstruction causes a heading up, which results in a breaching of the bank, often an artificial flood bank, and the river takes another course. The prime cause of such wandering is that the river is so situated as regards the bed-fall, the quantity and nature of the silt, and the manner in which freshets occur, that it is adding to its bed rather than scouring it out, and the most

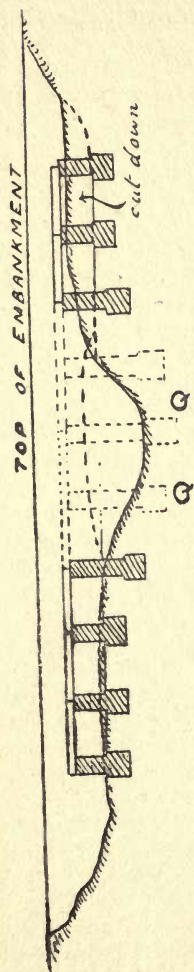


FIG. 9.



FIG. 10.

serious cases, generally, are those of large rivers which are kept between high flood banks. The river continues to raise its bed, the inhabitants go on raising the banks. The higher the banks are raised the deeper and more regular is the flow, and the more the river deposits silt, raising its bed still higher. Probably the worst of such cases occur on some of the rivers of China. But the same thing may occur naturally. The silt which is deposited on and a little beyond the banks is not subject to scour afterwards, and in a country of small rainfall, or where a well-distributed rainfall gives continuity to vegetation, such banks may be fairly stable. They restrict the river, which flows deeper than before, and therefore, on the average, more slowly. More silt is therefore deposited on the bed, and the river with its banks is at a higher level. Its course, once that of least resistance, is no longer such, and when the river overflows near a course of less resistance it may follow that course, either all at once, blocking the old course, or gradually, using the new channel at first as a flood channel or "spill," afterwards as the principal channel, and, finally, as its sole bed. The sketch (Fig. 10) shows diagrammatically four successive stages before the river takes a new course.

THE ACTUAL PROBLEM.

Leaving the study of what happens in the case of a great river flowing through a wide plain, let us take the case of a stream in a valley sufficiently well-defined to restrain its course within moderate limits of deviation. First we may, if other circumstances allow, reduce the chance of trouble happening soon by a careful selection of the site, choosing a position near the downstream end of a straight reach, preferably one that is nearly parallel to the general course of the stream, and one the cross-sections of which show considerable falls towards the stream. Such a reach may last

many times as long as other reaches. In a narrow valley, however, and when the stream is small, it may be better to choose a diagonal reach which can be crossed by the road more conveniently. In such a case it may be good economy to spend some money on the protection of the outer bank of the bend above the bridge. Generally, a study of the course of the stream near the proposed site should be made, in order to see whether that site is likely to be one of the pivots about which the bed of the stream shifts, and therefore likely to move more slowly than other parts of the course. These considerations apply more particularly to new countries, but in settled countries, too, have

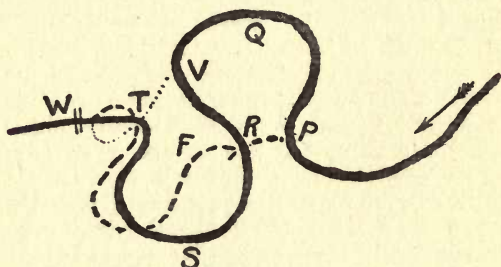


FIG. 11.

considerable force on waste lands, such as some moorland valleys where no control of the course of the stream is attempted. The tendency to wander is in proportion to the flatness of the valley, lengthwise and across, and depends, too, upon the relation between the fall down the valley and the fall towards the stream. It must also be noted that the stream running down a steeper part of the valley into a flat part will enter the flat part with a velocity which will make its attacks on the banks at bends fiercer than usual for some distance downstream. In such a case, and in some others, the *extreme* downstream end of a straight reach may

be a bad site on account of the tendency of the stream to cut back its bed.

This brings us to a consideration of the effects of straightening a stream, by making short cuts between bends. The way in which this may occur naturally has already been outlined; but whether it happens naturally or artificially, the possible effect on sites below it has to be considered. If a stream has a bend half a mile long between two points while the straight distance is a quarter of a mile, by making a short cut we make the slope or fall twice as steep, and increase the velocity. A straight piece of the stream approaching the bridge with the higher velocity may be more troublesome to deal with than the winding stream would have been. It is far easier to cajole than to coerce running water.

In the diagram (Fig. 11) it is better to make a short cut P R than to allow the stream to make one at V T. First, P R is in the direction of the bridge (at W), and later on, when the curve has moved to the position of the dashed line, there may be another cut, F T, natural or artificial, directly towards the bridge. Secondly, the total fall from P to T is only made about twice as steep by the short cut P R, at any rate at first; while the short cut V T replaces the length V R S T, and the velocity is likely to be very great. Lastly, the cut V T will cause a strong set of current, in the direction shown by the line of dots, where it may result in the bridge being outflanked or the abutments undermined.

THE BRIDGE AT A BEND.

Supposing, now, that the site is fixed, by necessity or selection, and that it is on a bend where the scour is likely to be great, and a strong attempt will be made by the stream to shift the bend many yards within a few years. To protect the bend by pitching is not necessarily the most economical or the

most sure way of meeting the difficulty. Rivers have a way of treating the end of the pitching as they would have treated the abutments of the bridge, and a large amount of pitching may be needed.

Often it is a better plan, particularly on large

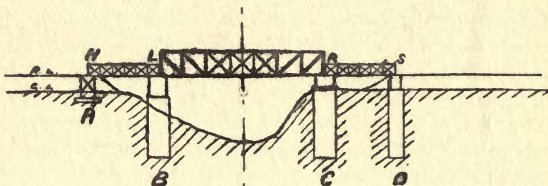


FIG. 12.

streams, to place the transverse centre line of the bridge not in the centre line of the current, but some way towards the bank which is on the outside of the curve. Where the movement is slow this may be enough in itself. A further precaution, necessary where the movement is considerable, is

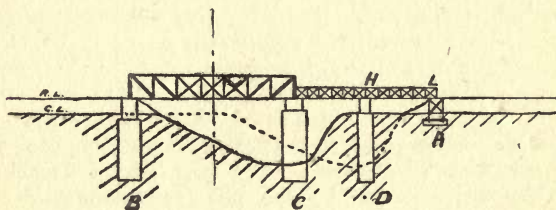


FIG. 13

to make the abutment on that bank in the form of an abutment pier. In the case of an arch bridge it may be necessary to make it so that it will be stable without having earth behind it; but, especially if the erosion is never long-continued, it may be sufficient to make it so that another arch can

quickly be built against it. In the case of a girder bridge, it is chiefly a matter of making foundations to a depth which would be suitable for a pier in mid-stream, and this is, of course, essential also in the case of an abutment for an arch.

If the movement of the curve is likely to be fairly rapid, so that in ten years or so some additional work may be called for, a girder bridge will probably be more suitable than an arch bridge. In the case of a fairly long bridge it may be a matter of bringing one span from the inside bank to the outside bank. A bridge of six spans would in such a case have to be made as a bridge of seven spans. This, however, involves the abandonment of an abutment, or an abutment pier, or the removal of its material to the other side, and in most cases the difficulty will best be met by making both abutments with approach spans, the outside of the curve being pitched if necessary. The removal of the approach span on the inside of the curve, and its erection at the other end of the bridge, would sometimes carry us as far into the future as we need to see. See Figs. 12 and 13. The pier can easily be moved if made in the form of a steel trestle put together with bolts. But if the movement is likely to go beyond the stage shown in Fig. 13, it is clear that the long span may eventually be wasted. If such movement is anticipated, it is better to make some such arrangement as that shown in the diagram (Figs. 14 and 15), in which case the span is shifted to the new position. Both trestles A and F are moved to new positions, and a new solid pier is sunk at M. The trestle G should be made of sections suitable for other local purposes, or it should be of quite a temporary character. Trestles, or screw piles, would be used instead of solid abutments for the shore spans. The girders would be so built as to be easily moved, a matter of no difficulty and small additional expense.

The writer has been concerned in the design of a bridge which was to be built at a bend of a river flowing through soft ground, and in this case one abutment was designed as a pier with deep foundations. Pitching was also to be done, the idea being to keep the bend at its present stage as long

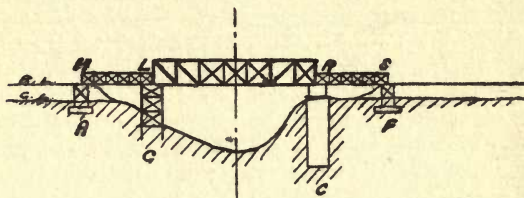


FIG. 14.

as possible, after which an extra span, not necessarily a long one, could be added from the abutment pier to a new pier to be built further on.

BRIDGES ON SCREW PILES.

A very simple and effective way of applying the principle is to make a girder bridge resting on screw

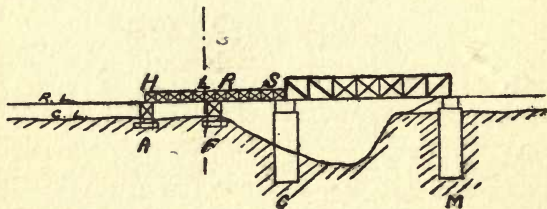


FIG. 15.

piles. Long piles are used at G and C (Fig. 14) in the first instance, and those at G can be removed to M (Fig. 15) when the girder is taken to the other end. If necessary they can be lengthened

and driven down deeper later on. Screw piles might be used in bridge work more than at present.

The iron screw piles of the old Coum Bridge at Madras, recently taken up after fifty years' service, were in a very good state of preservation, and in marked contrast with the girders. A point to be remembered is that if the bridge, at a bend, is one of many spans, it is worth while making the shore

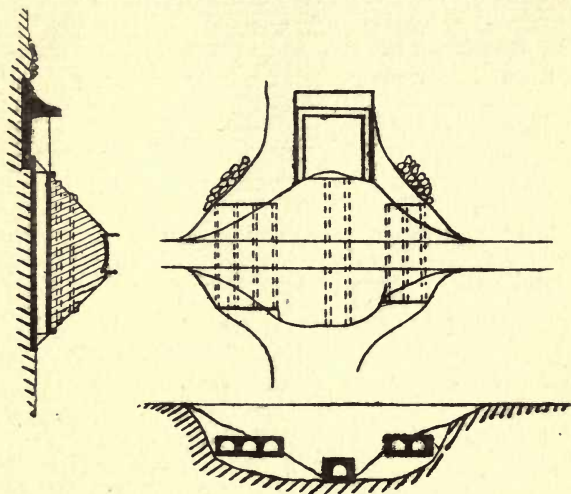


FIG. 16.

spans the same length as the others, even if the probability of having to shift one girder is very small.

THE POOLING METHOD.

While the measures just described are more particularly applicable to the case of a bridge built at a bend in a large stream the shifting of which is comparatively slow, they may also be taken into consideration when a bridge has to be built at a

somewhat unstable site on a smaller stream. In such a case, however, the relatively small cost of protecting the banks, and the possibility of coercing the stream if necessary, alter the general position a good deal. What is often a better way of dealing with a small stream, the wanderings of which take place within well-defined limits of deviation, is what we may call the "pooling method." It consists in taking the earthen embankment right across the valley bottom without making an ordinary bridge either for the present course or the future

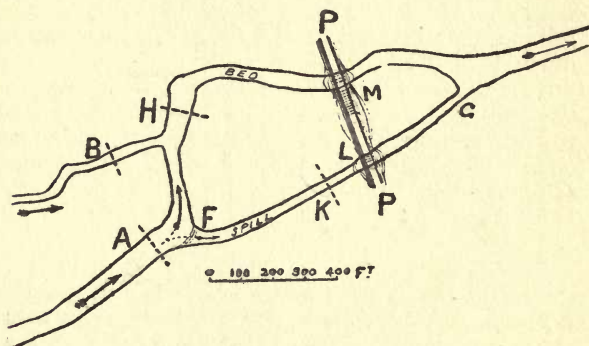


FIG. 17.

course of the stream, but providing instead a sufficient number of small spans to take the whole flow.

The cost, if we use quite small spans, may be much less than that of an ordinary bridge, in spite of the greater total width of waterway necessary in some cases—not all—and in other cases the pitching of a part of the embankment. The floors of the vents being placed at a level well above that of the old bed of the stream, there will be pooling up. If, however, the pooling is only intended to take place during floods, and the land is at other times under grass, for instance, we may provide a

vent at a lower level, sufficient to take the normal flow (Fig. 16).

It may be necessary to check the velocity of the stream through this vent under heading up caused by floods, but floods do not always increase the effective head. Sometimes they reduce it, some obstruction below the bridge being a greater check than the bridge itself. When a considerable amount of pooling cannot be allowed, it may be possible to get something of the same effect by making an artificial channel near the embankment, so that wherever the stream approaches it may turn and find an outlet through the vents. The design for a perennial stream would necessarily differ from that for an occasional torrent. To meet the case of a site where the silting is considerable and rapid growth of bushes and other plants takes place, grouping of the vents may sometimes be necessary, in order that the stream may establish definite channels and keep them reasonably clear.

A CROSSING AT A SHARP BEND.

Fig. 17 is a plan of a site where it was recently proposed to bridge a stream which, at any rate at this place, is of the wandering type. The stream was already forming a "spill" at the place marked F, while it had been intended to place a bridge of two spans of about 35 ft. at the place marked H, and a culvert of 12 ft. span on the spill F G, at the place marked K. Estimates were, however, prepared for an alternative design on the pooling system, and it was proposed that, as the season was too far advanced for the bridge to be built immediately, the stream should be encouraged to make the short cut already heralded by the spill. The best way to help a spill to develop is to make a deep cut in it where it re-enters the stream. For the rest, it was proposed to abandon the projected bridge on the bend, to place a main vent of about

20-ft. span across the spill at L, and to make a number of other vents, M, to discharge the water from the pool in times of flood; the embankment being carried right across. These smaller vents, about 15-ft. span, would provide the waterway needed at considerably less cost than that of the same waterway in two spans. An alternative would have been to build two bridges, one at A and one at B.

It sometimes happens that a costly bridge is built when a much more simple crossing would be more in keeping with the resources of the neighbourhood and the nature and amount of traffic. More often it happens that serious inconvenience is suffered for many years because it is assumed that the only way to make an improvement is to build a costly bridge. Yet in many cases a very small expenditure would provide a crossing which would be an important improvement.

FORDS.

A good many fords would be much improved by a little work with spades and potato forks. Here the pooling principle applies. The scour above the ford should be deepened so that it may check the current from above, distribute the water better, and spill it gently over the upper edge of the ford. The stones should be spread so as to get an even depth, and those large enough to be stumbling-blocks should be buried. There are many fords which themselves offer no great obstruction, but have very steep or rough approaches. These may often be eased a little and made harder, but they should not be carried into the ford so as to narrow it. On the contrary, many fords could be improved by a little widening.

The next step is to recognise the principle of the smooth spill. If the biggest stones are all placed together along the downstream edge of the ford they will tend to keep the whole bottom at the same

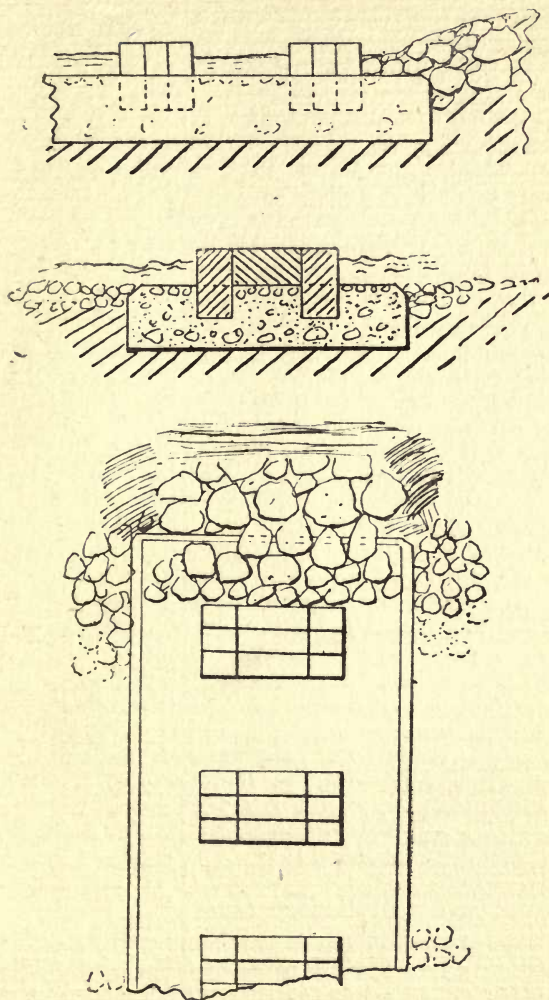


FIG. 18.

level, and if well arranged will allow the water to pass between their gaps, over stones at a slightly lower level, during dry weather. This is better than the simple stepping-stone idea. This principle, a little further developed, brings us to a cheap and simple work, suitable for crossings of village streams, and one which is self-clearing, or can be easily cleared by passers-by (see Fig. 18), in which the idea of built ramps is also brought in. Another way, suitable where materials for making concrete are at hand, is suggested by the type diagram (Fig. 19). The place is roughly prepared, and the first layer of concrete brings it up to the overflow level. Drain pipes are then placed on the concrete, and more concrete is rammed over them. A row of single pipes suffices for pedestrians and cyclists, and the smallest size will usually do. For greater lengths it is better to use pipes of larger diameter, which will be less likely to choke. Sometimes a single pipe would carry the dry-weather flow of a village stream, but it is not used, on account of the difficulty of keeping it from choking. This may be got over in most cases by making a small dam of stones and clay upstream of the ford, deepening the bed of the stream above it, and carrying the pipe from a point well below the surface of this pool. The pipe should be on one slope, and without a bend, except at the entry, so that it can be cleared easily by means of a hop-pole or beanstick. Without interfering with the character of the crossing as a ford during freshets, this device may be developed into the inverted syphon type for dry-weather flow, providing a drinking trough for cattle or a dipping place for the inhabitants of neighbouring cottages. (Fig. 20.)

THE "IRISH BRIDGE."

A good cart crossing is provided by that development of a ford which is sometimes called an "Irish bridge." The outline may be that of a segment of a circle for quite small streams (dotted in Fig. 21),

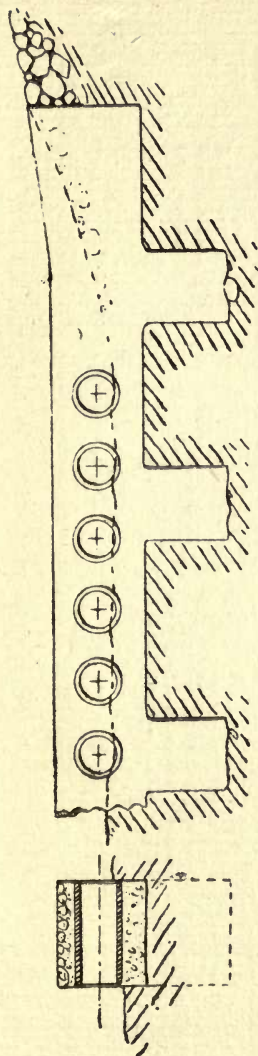


FIG. 19.



FIG. 20.

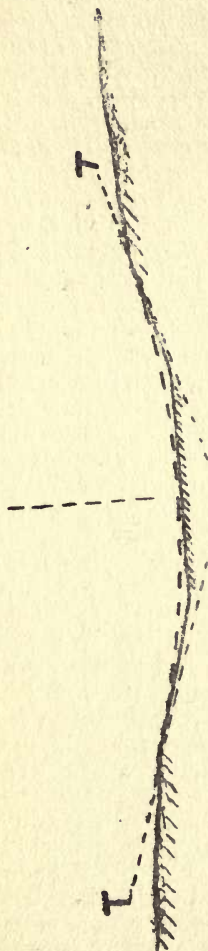


FIG. 21.

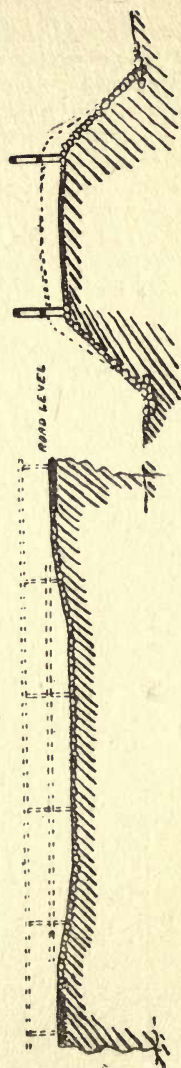


FIG. 22.

or where there is no footbridge, because it is then easier to step across the stream in dry weather; but for somewhat larger streams, and generally where there is a footbridge, the form shown by the full line in Fig. 21 is preferable, since it gives a smaller maximum depth. The largest stones should be placed at the downstream edge, lengthwise with the stream, and it may be necessary to build a small retaining wall, and to provide random blocks or stones to receive the water as it pours over the edge.

THE ROAD DAM.

Where a road embankment crosses very flat lands liable to floods, the "road dam," as it is called in India, may be an economical means of providing waterway, and, anyhow, be a very reliable safety overflow in case culverts are choked. When the difference of water levels on the two sides of the road is small, which is often the case, the water has only a short way to fall, and it may not be necessary to pitch more than a little of the embankment near the top. If suitable stone is scarce, and the road dam is not likely to be needed except in unusual floods, it may only amount to this, that the level place in the road is also made the strongest, the road margins as well as the crust being made up with broken stone and binder, well rammed. Usually the road is definitely depressed for a foot or so, and sometimes both approaches to a bridge which may prove insufficient for the discharge are made as shown in Fig. 22. Posts should be provided to mark the edges, especially if the water is likely to reach the level of the road on the downstream side, which is often the case. The length is usually much greater than shown in Fig. 22.

A "perforated road dam," as it is sometimes called, is really a series of culverts through an embankment. If there is no embankment the structure is a bridge or causeway. This type of crossing is a very useful one, and ought often to be brought

into competition with other types. If the embankment is pitched, so as to serve as an overflow in case of need, the capacity of the culverts may be made barely sufficient to pass ordinary floods (Fig. 23). If the earth of which the embankment is made will not stand except at a very flat slope, the bottom of the embankment is wide, and culverts relatively expensive. In such a case the kind of crossing shown typically in Fig. 24 may be an economical alternative. The slabs may be of stone, or ferro-concrete, or they may be spans of I-beams supporting a ferro-concrete or trough floor, according to the loads to be carried and the relative costs of different materials. If such a crossing is found to be too costly as a dry-shod crossing, it may be put back to an earlier stage of its evolution, and, while playing the part of a bridge proper at ordinary times, it may become in times of flood a ford relieved by under-vents. Supposing that the maximum discharge requires an aggregate opening 200 ft. wide and 4 ft. deep, it may be good enough to make the twenty vents $2\frac{1}{2}$ ft. high, instead of twenty vents 4 ft. high, designing the platform to withstand floods. This will give us a ford about 18 in. deep if the maximum flood is equalled, and fords of less depth on occasions, the number of which can be easily estimated by local inquiries or data as to floods.

The extra depth of slab that is needed at the edge of the floors may, in the case of a ferro-concrete slab, be gained by developing it into a beam, the depth of which is given by making it a part of the blocking course, so as not to reduce the area of the vent or add to the heights of the piers. It is worth noting that in the case of a crossing which consists of an earthen embankment pierced by culverts the cost is often needlessly great because it is forgotten that the necessary thickness for the slabs or arches which form the roofs of the culverts is very much less than it would have to be if these slabs or arches

were just under the crust of the road. The load on a slab roof buried under 10 ft. or so of earth is that due to the depth of earth—say half a ton per square foot—and another 3 cwt. or so per square foot due to the heaviest possible axle-load on the road. Only a small proportion of the whole is live load, and there are no appreciable shocks. The thickness is a matter not of strength but of the minimum consistent with stability. Corrugated iron culverts will last a considerable time, and may do good service when the money for solid work cannot be found.

THE INVERTED SYPHON.

A device which deserves more attention than it receives is that of the culvert or pipe connecting a pair of wells. A great deal of damage to road embankments is caused sometimes by the rush of water into a culvert at one end and the rush out of the other end. We can get over the rush into the culvert by the plan of raising the sill, when the water is drawn from a shallow pool which checks the rush and scour. This does not help us at the outlet, however. Here the best plan is to make a well up which the water will rise, falling harmlessly over the edges, or, if the edges are below water level, bubbling harmlessly upward and flowing away in the general sheet of water without scour (Fig. 25).

This type is not much used, though it seems to be of great antiquity, since it is the traditional type of outlet through tank bunds in India. The writer has strongly advocated it for drops on canals, and believes that the two basic ideas are more applicable to bridge design than is usually supposed. The basic ideas are (1) that when the water flows from a higher to a lower level we should deliver it vertically, either upward or downward, and (2) that while it is passing our masonry work the water should flow at the highest velocity which the materials will stand, because that means that it flows

in the smallest possible stream. When we build a bridge which fully spans a stream and hardly interferes with its flow, these principles do not come in. But they come in in many other cases; and where



FIG. 23.

it is allowable to head up and attain a high velocity, we may be able to economise in masonry if we can get over the ill effects of scour.

Supposing that we find a place in a natural stream where there is a fall of 5 ft., or where that



FIG. 24.

fall can be imposed. If the stream is one of high velocity we may gain little or nothing by increasing it, because we must not subject our masonry to more than a certain velocity. But if the stream is a sluggish one we may perhaps, within the

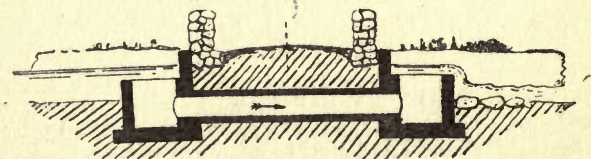


FIG. 25.

allowable velocity, increase its speed to double or treble and reduce its actual controlled size to a half or a third that of the natural stream.

This method, belonging to our fifth primary type, is not usually applicable except to canals or to streams with regulated flow. It may, however, be applied to streams which are liable to floods, or it may be developed as a bridge for ordinary occasions, and, in addition, as a weir over which flood waters may pass. Fig. 26 is a diagram of the type as adapted

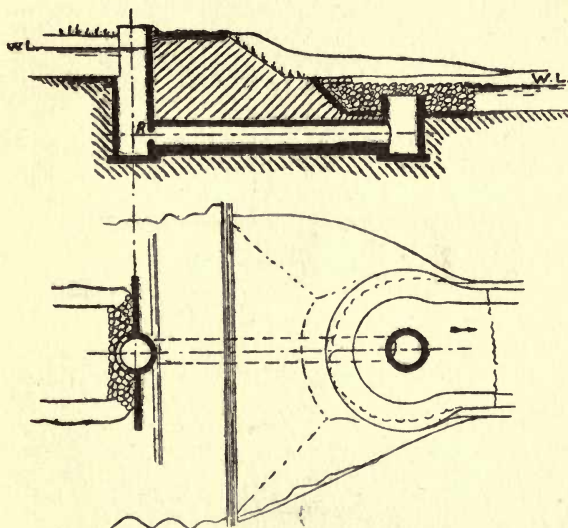


FIG. 26.

to suit an embankment crossing; not necessarily with pooling up, for advantage may be taken of a natural fall in the bed of the stream. In other cases pooling up may be allowed, as in the case shown typically in Fig. 16.

The diagram Fig. 27 shows the type we are now considering carried out in masonry. The problem is regarded as that of providing a stilled approach,

a rapid passage for the water, and a seething delivery with no definite set of current. A bridge of, in this case, three spans may be made from F to G, by making this part a little wider; or it may be made with shallow foundations, shown by the dotted lines in the figure, in addition to the work regarded as a fall.

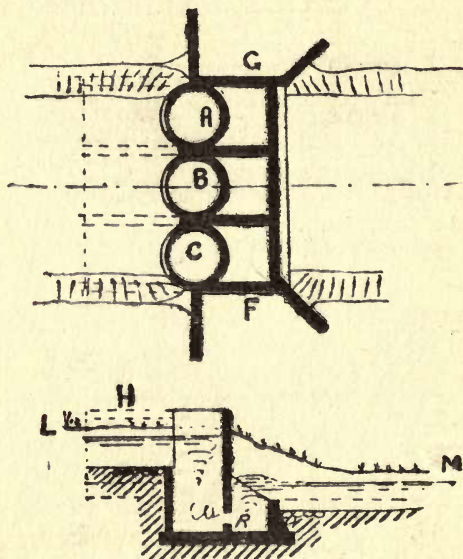


FIG. 27.

The estimates would compare thus: (A) the cost of a simple bridge, with foundations to resist scour, and with more or less protection of the banks above and below it; and (B) the work as suggested, with whatever additions may be needed for a bridge of the required width. The narrower the bridge needed, the more chance has (B) of competing with a bridge of an ordinary type, but it must be clearly

understood that while the elements of this method may be found in various designs, the method itself is only directly applicable in special circumstances. In the Figs. 26 and 27 the openings at R are made of such a size that they will just pass the maximum

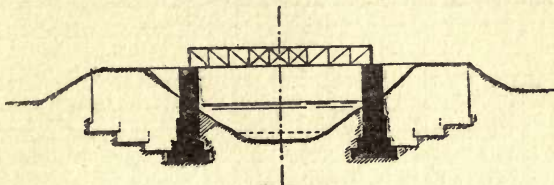


FIG. 28.

flow with a head up to the maximum allowable water level above them.

THE "OVERALL" SPAN.

It remains to consider here one other matter of principle which is not always grasped by beginners. This is that it is sometimes an economy to make a long span with very small abutments rather than

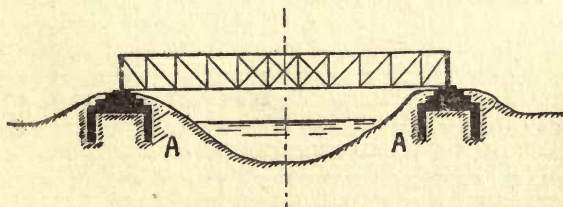


FIG. 29.

a short span for which high abutments with deep foundations would be required (see Figs. 28 and 29). In the case shown the canal will be under regular supervision, and any extraordinary happening at the foundations, A, would be noticed. For

moderate loads the cost of the large girder and small foundations may be less than that of the small girder and heavy abutments. This does not, of course, apply to spans of more than some 60 ft. to 100 ft., according to the nature of the traffic, because for longer spans than this every additional foot counts heavily in the cost, except for very light loads.

IMPACT.

As regards highway bridges, impact is often little more than a bogey. For the present purpose it will be sufficient to give the principal reasons why it is not necessary, as a rule, to make any considerable allowance for impact, the effect of which is best suggested by calling it "the suddenness with which a considerable proportion of the load has come upon the bridge."

In the first place, we have often the over-ruling consideration that the swiftly-moving loads are much lighter than the slowly-moving loads. Another consideration, and a dominating one in the case of a town bridge, is that the crowd load is usually the maximum load, and there is then no possibility of impact.

For shorter spans and narrower bridges a procession of swift motor cars, even if they were given an impact allowance of 50 per cent, would not give so severe a loading as loaded motor wagons, or even one wagon; and the rubber-tyred motor wagon travelling at 15 miles an hour would be a less severe load than a traction engine, even if we gave it a large impact allowance. There is another very important consideration that must not be overlooked, especially when the practice of allowing for impact in the design of railway bridges is regarded as a kind of precedent for making a similar allowance in the case of a highway bridge. This consideration is that the proportion of dead load to live load is usually very much greater in a highway bridge than in a railway

bridge. The effect of this is twofold. First, there is in the highway bridge a relatively large mass of inert matter which greatly deadens the effect of a sudden application of live load: the shock is absorbed by the mass. Secondly, the fact that the girders (to take the simple case of a girder bridge) are upholding a relatively large dead load means that they are relatively stronger to resist deflection by live loads in excess of that allowed for. If the stress in the outermost fibre of the flange of a railway girder is $1\frac{1}{2}$ tons per square inch before the train comes on to it, and 5 tons per square inch when the train has come on to it, we have a sudden increase of stress from $1\frac{1}{2}$ tons to 5 tons per square inch. If, on the other hand, in the girder of a road bridge the stress is $3\frac{1}{2}$ tons per square inch before the load comes on, and 5 tons per square inch after it has come on, the increase is only from $3\frac{1}{2}$ to 5 tons per square inch. The proportion is as from 21 to 70 in the case of the railway bridge compared with that from 21 to only 30 for the highway bridge. For quite light bridges which will be used by motor vehicles travelling fast, the "kick" after release of load may be of some importance if the dead load is very small.

MAXIMUM LOADS.

As regards the effect of a crowd load, if we compare it, taken as 80 lb. per square foot, with a traction engine regarded as 16 tons of concentrated load, we find that the limiting span is just about 90 ft. for a ten-feet width of road. Loading equivalent to a central load of 12 tons would equal the crowd load on a span of about 67 ft., and be more severe for smaller spans.

The maximum loading on a highway bridge may be calculated as equivalent to a single concentrated load, or as a distributed load, for most purposes of general comparison, and when the most severe main girder load has been thus found, the actual loading for the particular kind

of road train or vehicle may be worked out in detail. Some other kind of vehicle may, however, give the heaviest loading on a cross-girder, usually an axle-load, and the front roller of a steam roller may give the most severe floor load between cross-girders, under some conditions. Such points cannot be pursued further except in reference to definite designs, or at least well defined types of bridges. It is, however, a matter of general principle to consider how the loading may come on to the bridge as regards its centre line.

THE LOADING AS REGARDS THE CENTRE LINE.

For instance, we must allow for the vehicles on a bridge with a roadway 12 ft. wide being nearer one side than the other, and we must allow for tilt due to camber, as well as for that due to a weak spring. When effects such as these coincide, which they tend to do, they may be important, especially if eccentric loading of the vehicle itself throws the weight still further to the same side. If one package among a number is heavy for its size, it is best put on the off side, and a package bulky for its weight is best on the near side, the incentive, from the point of view of the owner, being that camber tends to throw more weight on the near-side springs and wheels than on the others, and that a bulkily laden vehicle loaded down on the near side and swaying on a cambered road is unduly severe on the near-side spring, and may cause damage to the load itself by striking against an obstruction. Another point, as regards maximum loading, is that the width of our bridge will allow of certain loadings according to whether it permits of the passage of two lines of vehicles or of one line only, and that what these vehicles may be depends on whether the bridge is scheduled against traction engines, or against these and heavy motor cars, or whether it is a full highway for all vehicles. Very often

the ordinary steam roller of the country gives the maximum loading. As regards the maximum loads permitted we must allow for these being exceeded in practice.

The allowance that must be made for one girder at a time having much more than half the load is greatest when the road is a good deal more than wide enough for one vehicle, but does not allow two to pass, or is nearly, but not quite, wide enough for three.

Fig. 31, compared with Fig. 30, shows how the actual live load which can come upon one girder

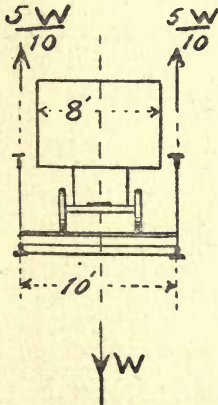


FIG. 30.

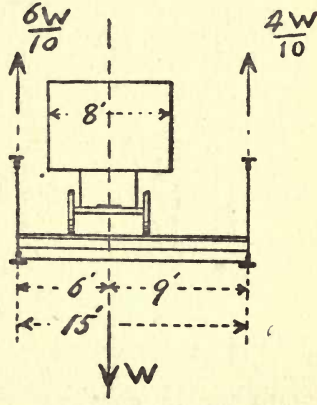


FIG. 31.

is increased by 20 per cent by having a road 5 ft. wider than is necessary for the vehicle. Fig. 32 is a study of the effect due to the tilting of the vehicle. The camber shown, though not suitable, is by no means unusual. The increase due to camber alone is about 5 per cent. If the centre of gravity (P) of the load and vehicle were 6 in. to the left, about another 5 per cent would be added to the load on the left-hand wheel, and with

this total of 10 per cent some further tilt due to depression of the spring would occur. It is clearly necessary to allow, say, 15 per cent beyond the normal wheel load in such a case. It is seldom desirable to camber the surface of a road on a bridge more than a very little, but it is often done.

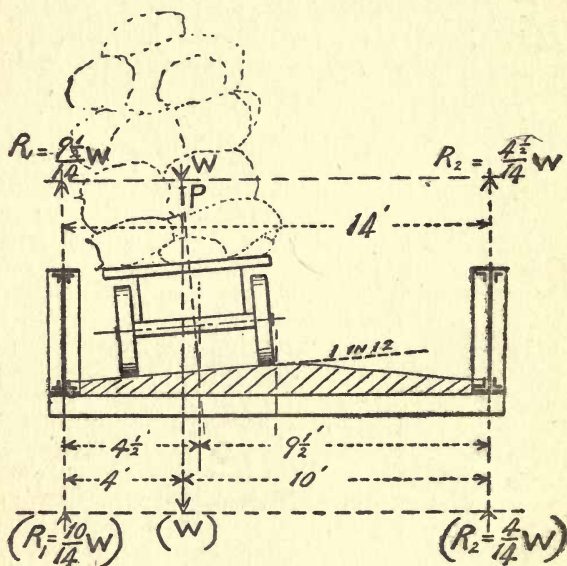


FIG. 32.

The greatest difficulty in assigning a maximum load is to decide to what extent the bridge under the heaviest line of vehicles may be loaded in addition by other vehicles, or animals, or a crowd. Are we to take the case of a traction engine and its trailers surrounded by a mob of strikers? Are we to take a light highway bridge in India, crowded

with a packed throng around a sacred elephant? Such cases are worst when the bridge has been calculated for one line of vehicles, but is nearly wide enough for two, the crowd load being then considerable. But young engineers must not fall into the error of allowing for the maximum possible loading for ordinary highway bridges of moderate span. It is *not done*. The chance of the maximum *possible* loading occurring is very small indeed, and the factor of safety is a good one. Important large-span bridges are quite a different class, and their design involves a quite different proportionate importance being assigned to the various factors.

EXCESSIVE METALLING.

Nevertheless, there are some kinds of excess loading which have to be considered. If the bridge has a metalled roadway it is desirable to guard against the overloading that may occur if unduly large quantities of stone are used in renewing it. It is reported that the recent failure of a suspension bridge—one cold morning when the cables were at their tightest—was due to the fact that according to standing orders, which it was assumed applied to the roadway on the bridge, definite quantities of road metal had been put into the road crust from time to time regardless of the rate of wear. There are sometimes reasons why the road crust wears more slowly on a bridge than on the adjoining portions of the road. In the case of a wide girder bridge, or a suspension bridge, it is especially desirable to have some measure of the depth of the crust, such as its level in relation to that of some definite plates or angles, or other blocking course.

Suppose that a bridge is 20 ft. wide and 60 ft. in span, an excess of 3 in. of road metal involves an excess load equivalent to a central load of about 8 tons.

SOME GENERAL COMPARISONS.

When a permanent bridge is called for, the great advantages of solid masonry arch bridges should always be kept in view. In a settled country, and in a situation where the bridge is likely to suit the requirements permanently, the lasting qualities of good masonry put bridges of this kind into a class by themselves, and most good masonry bridges would carry loads considerably in excess of those of the present day. In wilder places, where there is difficulty in getting the painting necessary for steel bridges carried out at the right times and in the right manner, the masonry bridge has the great advantage that it usually suffers little from neglect. For wide rivers which are liable to floods a bridge of masonry arches is sometimes at a serious disadvantage as regards the amount of obstruction which it causes; but if it is liable to be overtopped by the flood, it may be in better case than a girder bridge, which would either be one of light spans liable to be swept away or one of deep spans which would not allow of the passage of floating timber. In some countries there is often a very large amount of stuff coming down a river in high flood. The chief objection to short masonry bridges, especially those of one span, arises when there is a bump in the road caused by the rise of the arch. The difficulty is often more apparent than real, and many arches are placed too high because the designer of the bridge exaggerated the effects of heading up, or did not consider it worth while to incur the additional expense of making a small opening, or several, through the approach embankments.

Headway for navigation, when any considerable width is required, can only be gained by making the roadway over the arch at a considerably higher level than would be necessary with a girder bridge; but if the roadway is very wide, the advantage to

some extent disappears, because the cross-girders of the girder bridge have to be deep, unless they are very close together. In such a case a bridge of many beams close together may be suitable.

The thrusts from a single segmental arch with a very small rise are usually too great, having regard to economy and stability, for such a bridge to be a suitable type for a navigable waterway; but when the width of the canal or river is sufficient to demand the building of two spans, one of which would be sufficient for a vessel to pass through, the kind of bridge shown in the type diagram (Fig. 33) has considerable merits. If the middle span were much longer the thrust would be greater and a considerable amount of masonry in the abutments would be there to receive this thrust. In type shown in Fig. 33, however, the two side spans, cheap to build, usually provide effective abutments to take the thrust of the middle span; and even if we left thrusts out of considera-

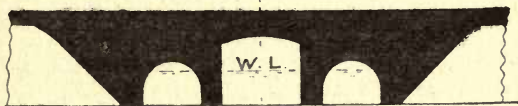


FIG. 33.

tion altogether, the bridge would not be far from the most economical design of its kind.

THE ARCH.

Great stability and permanence are valuable qualities of the semi-circular arch, and of segmental arches of moderate rise, and these qualities should not be lightly given up for the sake of saving a little material. Elliptic arches with cracks at the crown are sometimes to be seen, while such a thing as a crack is very rare with a segmental arch, though these are so much more numerous than

elliptic arches. The idea that an elliptic arch allows of economy of material is to a great extent a fallacy, having regard to the manner in which an arch fails, if it fails at all, and taking into consideration the loading that is really the most severe. No reference is made here to bridges of really large span.

In practice there is a tendency for the crown of an elliptic arch to be really a flat for some distance. Generally, the sharper the curve of the arch the better it resists single heavy loads and shocks.

In the case of a culvert under an embankment a single ring of half-brick thickness will often be enough, except at the ends, and provided that good mortar is available, or good bricks, for it is hardly necessary to have both.

If the culverts are large enough to be entered for repairs, the crumbling of a brick or two will not be a serious consideration. At the same time, if we are looking at the matter in the spirit in which a reference was made just now to masonry bridges, by all means let such culverts be made with no less number of rings of brickwork than will be *ultimately* economical and give the best security against accident. There are some cases in which we should aim either at great durability or at low first cost—not between the two. In situations where a possible breaching of the roads by floods may expose the culverts, these should be designed accordingly, for a breach in a road is a sufficiently troublesome matter in itself, and its repair could hardly wait for the rebuilding of broken culverts. In such a situation any temporary arrangement should be replaced by a permanent one as soon as may conveniently be done.

STEEL BRIDGES AND TIMBER BRIDGES.

What often determines the choice of a steel girder bridge is the consideration that its life is likely to be about as long as the period during

which it will be wanted, and that the cost is reasonable in the light of this fact. For ordinary highway bridges, however, away from towns, this consideration seldom applies, and bridges are replaced because they are too weak rather than because they are ugly. At the same time, a present saving is a very definite gain, and there is often a good deal to be said for a bridge which will last some fifty years.

We must draw a very strong distinction between bridges which are of sufficient size and importance and managed under sufficiently favourable circumstances to be regularly cleaned and painted and, on the other hand, highway bridges in thinly-peopled districts where the enduring nature of the materials when left to themselves is of greater importance. In this connection it is desirable to form a clear idea as to the possible life of a timber bridge, and to take into consideration the possibility of repairs to such bridges being made with local timber. The lasting qualities of steel compared with timber should not be exaggerated. The same consideration which may make a steel bridge more economical than the more enduring masonry bridge would, in some cases, apply with even greater force to the shorter-lived, but cheaper, timber bridge. For timber bridges of considerable span it is sometimes economical to use steel for the tension members.

For small span steel bridges, in rough countries particularly, liberal allowances have to be made beyond the theoretical scantlings of the members. There should be two kinds of allowances, that given by a definite minimum thickness and that given by allowing a certain thickness beyond that demanded by the calculations. We must allow for a skin of steel rusting and becoming useless except as a protection for the rest; or we may regard this skin as what will eventually be removed by occasional scaling or by cleaning when the bridge is re-

painted. If these allowances are made fairly liberally in the case of an N-girder, for instance, it may be found that the economical span for rolled steel beams is considerably greater than it would have otherwise been, since in this case the allowances have less effect. As to the N-girders themselves, the economical design of Westminster is not necessarily the economical design for the jungle or the Indian village. Steel girders for such situations should be so designed that they can be easily painted with rough appliances. This consideration, in conjunction with the matter of scantling allowances, may make a plate girder a suitable design for a larger span than those assigned to it in the light of experience in England.

FERRO-CONCRETE BRIDGES.

On the most pessimistic view—or almost that—ferro-concrete bridges may be expected to outlast steel bridges of the same or greater cost. On a more hopeful view they may last so long that they may prove satisfactory substitutes for solid masonry bridges. While the ferro-concrete arch may be, and no doubt often is, an inexpensive design, it can certainly be contended with much reason that where materials for making concrete are cheap there is seldom any considerable advantage in reinforcing the arches of small span highway bridges. For larger spans, and when, for instance, it is worth while making ferro-concrete ribs, the matter is on a different footing, and the use of steel may lead to economy by reducing the quantity of concrete used to an important extent. Where ferro-concrete seems likely to be specially useful for small-span road bridges is in those cases in which the roadway must not be raised nor the waterway (or the headway for barges) impeded. Here the type in which the parapets of the bridge are ferro-concrete girders has special merit for bridges of moderate width, through the rolled steel beam type—which dogs

several other types with a kind of steady persistency—might have to be considered for a similar crossing with a wider roadway.

Another useful type is the plain concrete arch with reinforced abutments, wing walls and parapets, the reinforced parapet and side wall combined offering the very important advantage of considerable height with only moderate weight and cost, making it possible for the arch ring to be protected by a considerable depth of filling. To gain height by earth and sidewalls, with some reduction of arch thickness, may be cheaper than to gain the same height by making taller piers.

The use of ferro-concrete in such a way that the abutments are developed into cells or stalls filled with earth for the sake of stability was first proposed, it is believed, by the author, who at the same time drew attention to the fact that ferro-concrete permits of the application of the cantilever principle to quite small-span bridges. Both these considerations are vital, and their recognition means that the use of ferro-concrete has brought in two new and distinct types: that in which the abutment is solid with the span, and may be weighted for stability, and that in which the bridge may survive without collapse the undermining or even destruction of one of its piers.



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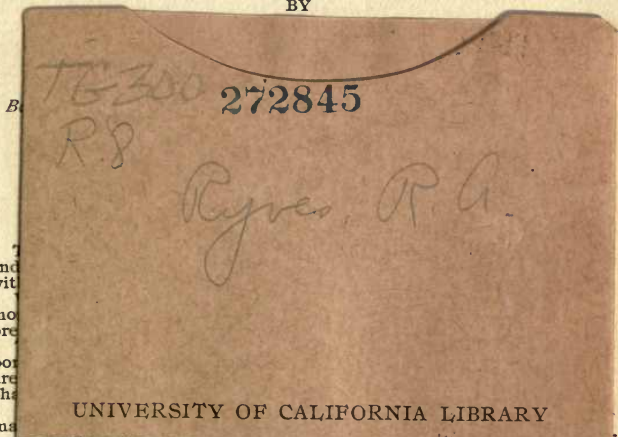
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Prominent amongst the additions in the present edition are the sections relating to concrete sewers, sewer ventilation and flushing, and the Public Health Acts Amendment Act, 1907, which embodies many important new provisions bearing upon questions of drainage, ventilation, and sanitary work generally.

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